

Acoustical Characterization and Efficacy Evaluation of Ultrasonic Pest Control Devices Marketed for Control of German Cockroaches (Orthoptera: Blattellidae)

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ABSTRACT Four models of commercially available ultrasonic pest control devices were characterized acoustically with sound level meters, sound spectrum analyzers, and an oscilloscope in connection with a signal averaging computer. Results indicated that the devices fell short of the manufacturer claims in both intensity of output and frequency regions of maximum energy. A single thickness (0.30 cm) of cardboard attenuated the output by ca. 70 dB. In these tests, ultrasound neither controlled nor repelled test insects nor increased their susceptibility to chlorpyrifos.

VIBRATIONAL WAVES of frequencies above the range audible to the human ear are generally referred to as 'ultrasonic,' and the term therefore includes all frequencies of more than 20 kHz. Because ultrasound is, for the most part, of the same nature as audible sound, the physics of its propagation are similar to those of audible sound (Schilling et al. 1947, Krasil'nikov 1960). While ultrasonic waves behave similarly to audible sound waves, their very short wavelengths accentuate some of the basic properties of all sound waves—i.e., they are highly directional at the source and are easily diffracted. Diffraction effects or reflection effects are the result of the interaction between the dimension of the wavelength of the signal and the dimension of the obstacle. If the wavelength is smaller than the obstacle, the signal will bounce off the obstacle and create a sound shadow behind the object. If the wavelength is larger than the object, the signal will appear to bend around the object. Because ultrasounds have very short wavelengths in comparison with audible sounds, they tend to be easily diffracted and attenuated by obstacles.

Reports on the biological effects of ultrasound have been used to support claims for the use of frequencies above 20 kHz to control pest populations (Allen et al. 1948, Frings et al. 1948). The use of ultrasonic sound (ultrasound) to effectively repel, mitigate, or control populations of insects within structures has, to this time, not been demonstrated scientifically. Laboratory experiments designed to measure the response of field-collected populations of the German cockroach, *Blattella germanica* (L.), to sound following exposure to seven sound frequencies failed to influence signif-

icantly the distribution of cockroaches in choice boxes (Ballard and Gold 1982, 1983a). These tests, however, were accomplished using steady-state pure tones emitted by a noncommercial device. In order to clarify the responses of German cockroaches to ultrasound, experiments were replicated, using commercial ultrasonic devices placed in large testing chambers. The results of these experiments indicated that German cockroaches apparently responded to ultrasound (as measured by slightly increased locomotion), but there was no evidence that either control or repulsion of German cockroach populations occurred as a result of ultrasound (Ballard et al. 1984). It has been hypothesized that increased cockroach activity could have been due to environmental stress. Vance (1983) demonstrated that stress induced by food and water deprivation for periods of 48 h caused increased susceptibility to chlorpyrifos applied topically to German cockroaches. The impact of stress resulting from exposure to ultrasound has, to this point, not been evaluated.

The purpose of our work with German cockroaches was to evaluate the effects of ultrasound emitted by commercially available ultrasonic devices with different signal frequency ranges, patterns, intensities, and attenuation potentials.

Materials and Methods

The ultrasonic devices included in these tests were provided through a contractual agreement with the U.S. Federal Trade Commission and included: Deci-Mate (Model 300D Ultrasonic Pest Repeller), Deci-Mate (Booster; Model 500C Ultrasonic Pest Repeller), Pest Sentry (Model PS-1500), and Pest Free. All devices were received in working condition, as determined by acoustical testing procedures.

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All acoustical measurements were made in a commercially constructed, acoustically isolated room. Measurements were made with a Bruel and Kjaer 2209 Sound Level Meter and a Bruel and Kjaer 1616 1/3 Octave Filter Set in conjunction with a Bruel and Kjaer 413B 0.32 cm pressure per random incidence microphone. The output of the sound level meter was led to a Wavetek 5820A Spectrum Analyzer. Additional acoustical measurements were made with a Bruel and Kjaer 2203 Sound Level Meter and a Bruel and Kjaer 4145 2.54-cm free-field microphone. The output of this array was led to a Tektronix 5110 Oscilloscope and a Nicolet 1074 Signal Averaging Computer.

Sound pressure levels (SPL's) were measured with the 0.32-cm microphone mounted on a goose-neck extender attached to the sound level meter. When used, the 2.54-cm microphone was attached directly to the sound level meters without the extension. Measurements were made at 0° incidence and care was taken to insulate the sound level meter and the pedestal on which the sound source was supported in order to minimize any acoustic reflection. All recordings with the 0.32-cm microphone were made in the peak and hold mode, while the readings with the 2.54-cm microphone were made in the fast response mode.

Peak output in decibels was measured with the 0.32-cm microphone in conjunction with the 1/3 octave filter and the spectrum analyzer. Measurements were made at the speaker (0 m). SPL measurements for each frequency band were recorded at 0 and 0.91 m from the sound source. Determination of sound attenuation over distance was recorded within the frequency band containing the peak SPL at 0, 0.91, 1.83, and 3.66 m from the sound source. Polar amplitude was recorded at the peak energy frequency in a 1-m circle around the sound source.

Duty cycle (pulse/time) and enclosure attenuation effects were measured with the 2.54-cm microphone array. Duty cycle measurements were made of the SPL envelope over time in order to visualize the on/off time of the ultrasonic pulses. Oscilloscope displays were printed with a Hewlett Packard X-Y plotter. Enclosure attenuation effects were determined by centering each ultrasonic device in the bottom of a 1 m³ cardboard box (0.30 cm thickness). The ultrasonic device was turned on, the lid of the container was closed, and SPL readings in decibels were taken at (0.12 cm distant) the box surface. The results of these readings were compared with readings taken with the ultrasonic device placed equal distance from the recording equipment, but outside the cardboard box.

The cockroach testing chambers used in these experiments were described by Ballard et al. (1984). A total of eight chambers were used with four arranged in each of two isolated rooms. Each chamber had a removable lid and was 1.22 m on a side. Chambers were set above the floor on 1.22-m lengths of pinewood (5 by 15 cm). Inside seams

were caulked and all surfaces were painted with two coats of white enamel paint. An electric shock barrier was located inside the chamber 15 cm below the top to prevent the escape of the test cockroaches. The ultrasonic device rested on a wooden shelf mounted in a top corner of the chamber. The shelf was angled to direct the sound beam to the opposite lower corner (ca. 2 m distant). In that lower corner, a 4-cm hole was drilled and fitted with a rubber grommet so a bottle pitfall trap could be attached. Chambers were provisioned with food (Purina Dog Chow) and water (glass bottle fitted with a dental wick) centrally arranged in direct line with the ultrasonic beam. Food and water were provided ad lib.

Field-collected German cockroaches were placed into the chambers before the ultrasonic devices were activated. The cockroach populations consisted of 50 adult males, 50 adult females (no ootheca), and 200 nymphs (third or fourth instars). This ratio (1:1:4) was based on extensive field collections and trapping studies which indicated that this best approximated the composition of actual field populations (Ballard and Gold 1983b). The cockroaches were allowed to acclimate to the test conditions for 24 h before the onset of testing. On day 1, the pitfall trap was opened and the ultrasonic device switched on. In the control tests, an ultrasonic unit was placed in the control chambers, but was not turned on.

Live cockroach counts were recorded daily in each cube for the 7-day duration of each replication. Counting was done in the dark using a flashlight to minimize disturbance of the cockroaches. Daily records were kept on the number of cockroaches caught in the pitfall traps. The mean percentage of live cockroaches caught per day was calculated from the number of cockroaches alive and the number of cockroaches caught in the pitfall trap. The data were analyzed by analysis of variance and linear regression following arc sine transformation of data expressed as percentages. Means were separated with Duncan's (1951) multiple range test.

Ultrasonic devices were randomly assigned test cubes. Trials were repeated until at least 10 replications had been completed with each of the three devices and the controls. The four replications with the Deci-Mate (Booster) used a single device, while the replications of the other brands and controls used at least three different devices with the same model number.

The SPL within each chamber, whether equipped with an active or inactive device, was measured with a portable Bruel and Kjaer Type 2203 precision sound level meter fitted with a Type 1613 octave filter and 2.54-cm microphone. Measurements were taken at the onset of each replication for both the treatment and control tests.

To evaluate the effects of ultrasound on susceptibility of German cockroaches to chlorpyrifos, 80 adult males (Orlando normal biotype [pesticide

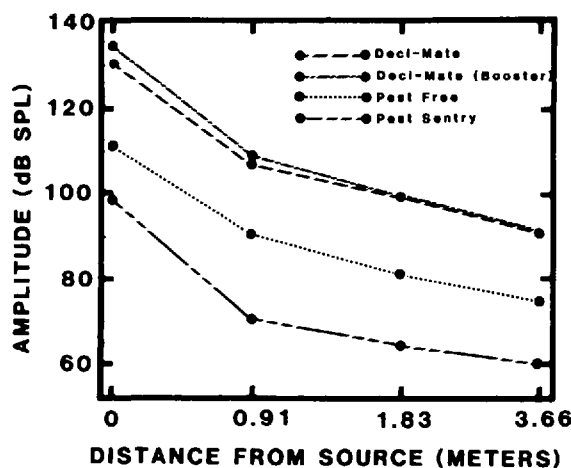


Fig. 1. Mean amplitude (dB SPL) of ultrasound through distance from the source for each of the four commercial ultrasonic models tested.

susceptible)) were held in the test chambers for 7 days. Five replications were performed with each of two test situations which included continuous exposure to ultrasound (Deci-Mate) and controls (no ultrasonic sound). On day 8, the male cockroaches were anesthetized with CO_2 and removed from the chambers for bioassay. Replicates of 10 males were treated with a 1- μl droplet of chlorpyrifos in acetone placed between the pro- and meso-thoracic coxae using a Hamilton Microlab P programmable micropipette. Six chlorpyrifos dosages (2–7 μl chlorpyrifos per gram of cockroach) and an acetone control were used. Numbers of dead and moribund cockroaches were recorded at 2, 4, 8, 12, and 24 h after treatment. Probit analysis of mortality data was used to estimate the LD_{50} values following correction of data by Abbott's formula (Abbott 1925).

Results and Discussion

Results of the acoustical characterization of the ultrasonic devices included in these tests are summarized in Fig. 1 to 3. The maximum output (SPL) for each test unit was at the speaker (0 m), with attenuation over distance following the inverse square law (ca. 6 dB SPL decrease per doubling of distance from sound source) (Fig. 1). Output from all devices tested was less than the advertising claims at the speaker or for distances up to 3.66 m. Maximum output for all devices was at ca. 40 kHz (Fig. 2), with evidence of frequency sweeping from 20 to 50 kHz. The output was directional for all test devices with a 20 dB SPL reduction at the sides of the speaker (Fig. 3), and maximum energy measured straight to the sound source. Pulse durations ranged from 2 to 14 msec with interpulse intervals of from 2.6 to 14.6 msec, depending on unit tested (Fig. 4).

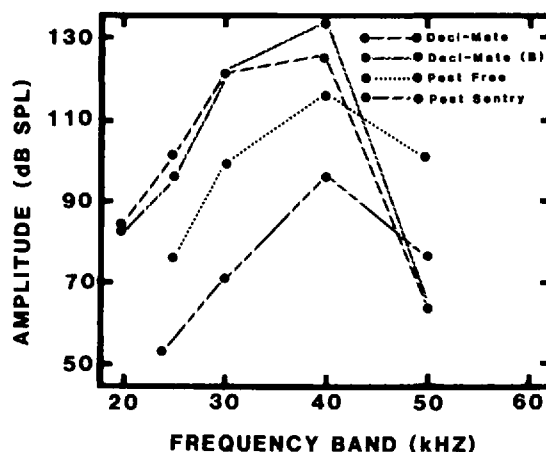


Fig. 2. Mean amplitude (dB SPL) at various frequencies (kHz) of ultrasound measured at the source for each of the four commercial ultrasonic models tested.

Among the most revealing results were the effects of the cardboard box on the attenuation of the ultrasound. Approximately 0.30 cm of cardboard attenuated the output of the devices by ca. 70 dB SPL from their peak output values.

There were no significant differences in cockroach mortality between the control units and any of the three brands, including Deci-Mate with the booster on, through 7 days (Table 1). High mortality of the field-collected cockroaches was evident between time 0 and the end of day 1. This mortality was similar among treatments and therefore had minimal effect on the outcome of the experiments. The results of the mortality testing were consistent with the advertised claims for ultrasonic devices in that they do not kill pests.

There was no significant evidence of heterogeneity in the percentage of live German cockroaches caught in pitfall traps among the three devices of each brand included in these studies. It was

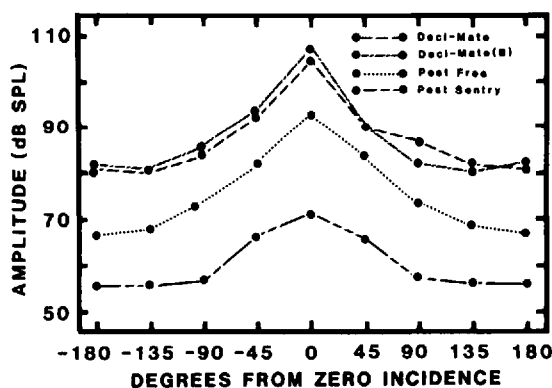


Fig. 3. Mean polar amplitude (dB SPL) at different degrees from zero incidence as measured at 0.91 m from the source for each of the four commercial ultrasonic models tested.

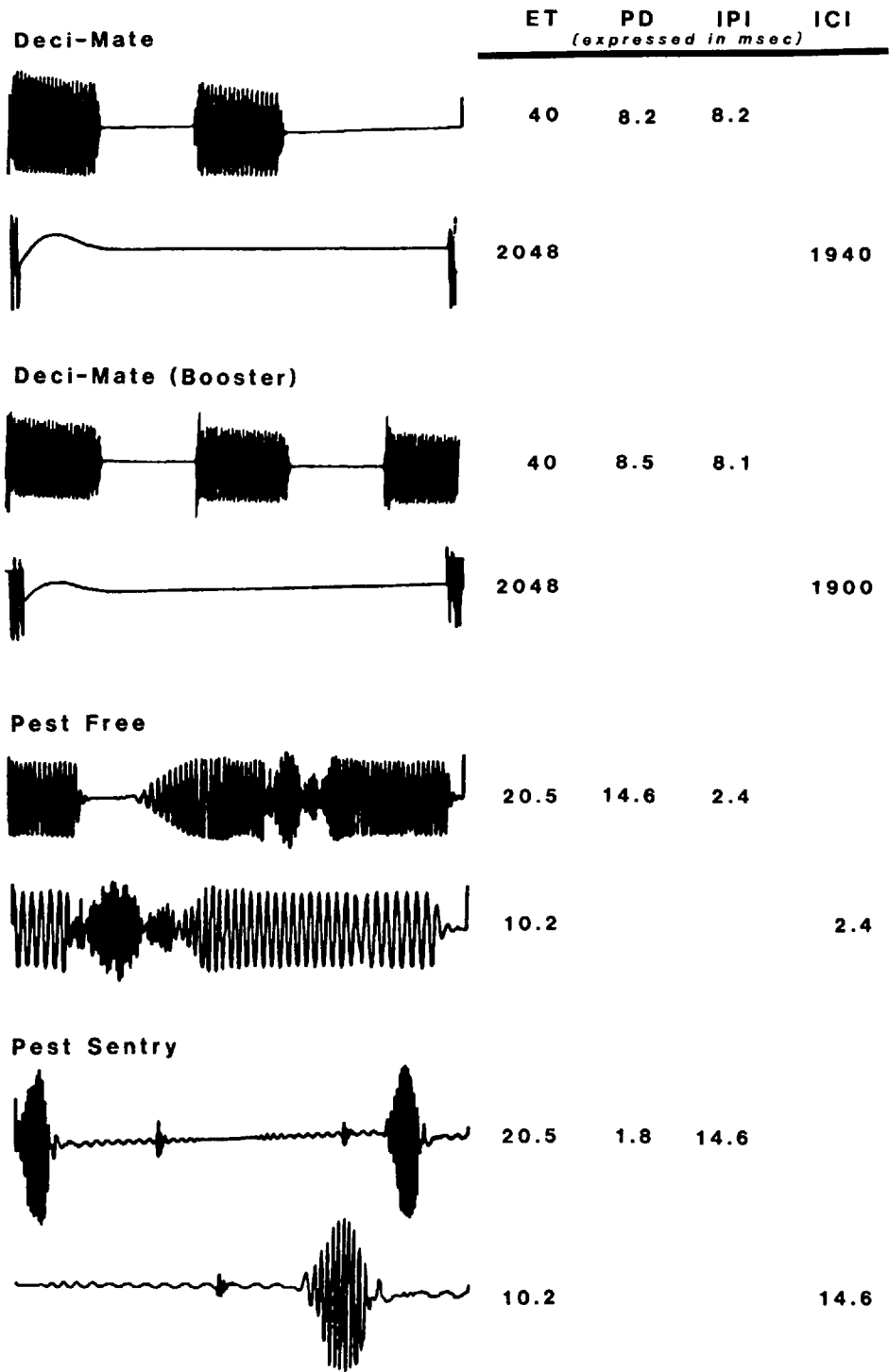


Fig. 4. Representative oscilloscope tracings for the elapse time (ET), pulse duration (PD), interpulse interval (IPI), and intercycle interval (ICI) from each of the four commercial ultrasonic models tested.

therefore possible to consider the results from all replications with a single brand on a daily basis as compared with other brands and the controls. We decided, however, to separate the results of the Deci-Mate with the booster (Model 500C) in order

to compare those results with Deci-Mate Model 300D, as well as the other two brands and the controls (Table 2). This decision was made on the basis of advertising claims indicating the greater efficacy of Deci-Mate with the booster on. There

Table 1. Mean number of German cockroaches alive either in test cubes or in pitfall traps

Test device	n ^a	dB	SPL ^b	Days						
				1	2	3	4	5	6	7
Control ^c	12	12.6	300	226.8a	215.8a	213.9a	209.2a	208.9a	206.0a	204.6a
Deci-Mate	10	46.0	300	204.9a	188.1a	189.1a	179.2a	175.2a	175.5a	176.2a
Deci-Mate (Booster)	4	56.5	300	221.5a	213.8a	206.8a	200.3a	195.5a	195.5a	195.2a
Pest Free	11	51.2	300	209.3a	205.7a	205.8a	208.9a	205.4a	203.5a	201.7a
Pest Sentry	11	28.0	300	209.0a	205.7a	205.8a	208.7a	205.4a	203.6a	201.7a

Means within columns followed by the same letter are not significantly different ($P = 0.05$; Duncan's [1951] multiple range test).

^a Number of replications with each replication initiated with 300 German cockroaches (50 male, 50 female [without ootheca], and 200 nymphs [third and fourth instars]).

^b Mean ultrasonic sound output was measured on two meters within a test chamber with a portable Bruel and Kjaer Type 2203 sound level meter with a Type 1613 octave filter using a 2.54-cm microphone.

^c An ultrasonic device was present in the control chambers, but was not turned on.

were no significant differences in the performance of either Deci-Mate model (Table 3). However, there were significant differences with Deci-Mate, Deci-Mate (booster), and Pest Free when compared with the controls and Pest Sentry on at least 1 of the 7 days of the tests ($P \leq 0.05$). Pitfall traps in the chambers with the Deci-Mate and Pest Free brands tended to have higher cockroach catches throughout the 7 days. Pest Sentry could not be separated from the controls on any of the test days (Table 2). This could be due in part to the lower output of ultrasonic sound when compared with the other brands.

When the mean of means of the percentage of catch of live German cockroaches was calculated for days 1 through 7 and the means were separated with Duncan's multiple range test, the Deci-Mate and Pest Free brands were significantly different than the controls and the Pest Sentry brand ($P \leq 0.05$) (Table 2). Based on the results of the daily comparisons, it would be impossible to conclude that the Deci-Mates or the Pest Free devices either repelled or controlled German cockroaches under the test conditions described. It does appear possible that the German cockroaches are capable of detecting at least a portion of the spectrum of ultrasonic sound emitted by the test devices as evi-

denced by a slightly greater (4–6%) trap catch. The results presented in Table 2 could thus be interpreted as statistically significant, but biologically unimportant in terms of the overall repulsion or control of German cockroaches.

The LD₅₀ for German cockroaches treated with chlorpyrifos following exposure to ultrasound for 7 days was 3.88 $\mu\text{g/g}$ as compared with 3.93 $\mu\text{g/g}$ for controls. There were no significant differences in susceptibility to chlorpyrifos as a result of exposure to ultrasound.

We generally concluded that the ultrasonic devices fell short of manufacturer claims in both intensity of the output and frequency region of maximum energy. The output of the instruments, while relatively high at the source, fell off rapidly when distances from the source were increased. This made it highly unlikely that the devices could provide a sound intensity sufficient enough to be perceived by insect pests over the areas (140–186 m²) indicated in the use directions. Because 0.30 cm of cardboard was all that was required to attenuate the output by ca. 70 dB SPL from the peak output values, the advertising claims that the sound would penetrate wooden doors, cabinets, and plaster walls (and control pests) should be considered as gross exaggeration.

Table 2. Mean percentage of catch of live German cockroaches in test cubes and pitfall traps

Test device	n ^a	dB SPL ^b	Days							% ^c
			1	2	3	4	5	6	7	
Control ^d	12	12.6	38.5a	23.9ab	18.5ab	12.9a	9.3a	7.7a	6.8a	16.8a
Deci-Mate	10	46.0	38.7a	28.5b	26.5b	18.0a	20.5b	15.1b	9.9a	22.5b
Deci-Mate (Booster)	4	56.5	38.3a	29.0b	20.0b	16.9a	14.4ab	17.5ab	13.6a	21.4b
Pest Free	11	51.2	40.1a	32.8b	24.0b	14.1a	16.2ab	10.1ab	7.6a	20.7b
Pest Sentry	11	28.0	27.8a	17.5a	11.5a	11.8a	9.5a	7.8a	6.1a	13.1a

Means within columns followed by the same letter are not significantly different ($P = 0.05$; Duncan's [1951] multiple range test).

^a Number of replications with each replication initiated with 300 German cockroaches (50 male, 50 female [without ootheca], and 200 nymphs [third and fourth instars]).

^b Mean ultrasonic sound output was measured on two meters within a test chamber with a portable Bruel and Kjaer Type 2203 sound level meter with a Type 1613 octave filter using a 2.54-cm microphone.

^c Means of mean percentage of live cockroaches in test chambers and pitfall traps for days 1 through 7.

^d An ultrasonic device was present in the control cubes, but was not turned on.

Claims that these ultrasonic devices are effective in controlling, repelling, or eliminating roaches and waterbugs also are unfounded based on the results of this research. Ultrasound was not effective in killing cockroaches confined with commercially available ultrasonic devices, nor was there any significant evidence that cockroach populations were susceptible to insecticide as a result of exposure to ultrasound. At best, cockroaches could possibly be moved to sound shadows within a residence, but this should not be considered control because the same population would still exist within the confines of the defined environment. Available scientific evidence thus indicates that ultrasound cannot be used effectively to control German cockroaches.

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